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BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

SUBJECT: Spacecraft Attitude Variations During the C' Mission External ΔV LOI Maneuver - Case 310

DATE: December 9, 1968

FROM: F. La Piana

ABSTRACT

A simulation of the C' Mission LOI maneuver was performed to evaluate spacecraft attitude variations due to center of gravity (C. G.) motion. External ΔV, closed loop steering and the Digital Autopilot simulations were used to evaluate two cases:

Case I: Vehicle aligned with the velocity-to-be-gained ($\overline{VG}$), then the thrust offset to go through the C. G. This produced maximum gimbal angle (attitude) changes of 1.3° and 1.1° in pitch and yaw respectively at a time of burn of 40 seconds. Subsequently, the C. G. motion is closely tracked.

Case II: Thrust, C. G. and $\overline{VG}$ initially collinear. The system accurately tracked the C. G. motion even when abrupt changes were used in the forcing function. Maximum gimbal angle changes of 1.03° in pitch and .15° in yaw occurred.

Neither case produces gimbal angle changes considered undesirably large.

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MEMORANDUM FOR FILE

I. INTRODUCTION

The purpose of this study was to evaluate the effects of C.G. motion, due to propellant consumption, on the spacecraft attitude during the C' mission LOI maneuver.

For this study, the command module guidance system, digital autopilot (DAP) and rigid body rotational dynamics simulations were used. These are part of the Bellcomm Powered Flight Performance Simulator Computer program. Vehicle parameters and trajectory data were taken from references 1 through 7.

II. SIMULATION METHODS AND ASSUMPTIONS

A. Guidance System

The LOI maneuver for the C' mission is programmed as an External ΔV type. The simulation used:

$$\overline{VG} = \overline{EVR} - \overline{EVS}$$

to compute the velocity to be gained. EVR is the External ΔV Vector (inertial) provided by reference 1, and EVS is the accumulated measured velocity increments.

The cross product steering law (with C = 0) reduced to

$$\bar{\omega}_c = K_1 \frac{\overline{VG} \times \bar{a}_T}{|\overline{VG}|\,|\bar{a}_T|}$$

the value of K_1 used was .1 for all runs.

B. Digital Autopilot

The DAP simulation used was that described in references 3,4,5,6 and 7. For this mission, $K \frac{TLx}{I}$ set to 13.5 was used, as is in the Colossus ropes. Since this is a CSM only configuration, the first order DAP filter was used with a cycle time of 40 milliseconds.

C. Vehicle Parameters

The basic thrust, ISP and mass data was taken from references 1 & 2. Mass at LOI start was 1946 and at end 1449 slugs. Thrust used was 20,500 lbs and ISP 314.1 sec. Figure 1 is a plot of C.G. offset in the pitch and yaw planes vs time. Two curves are shown for each plane; since both a 5 point table look up and a straight line procedure were used in the simulation, the dashed curves (A and D) represent a C.G. location movement having abrupt changes in direction. The curves B and C are a strictly linear model. The real case being between these two extremes.

D. Trajectory Parameters

Maneuver start and end state vector data was taken from reference 1. The External ΔV input was also provided by this document.

E. Thrust Alignment Procedure

Two methods were utilized and data is presented for both. It was desired to compare the results of both methods even though only one is to be used.

1. For Case I, the simulation is of the vehicle aligned in the direction of $\overline{VG}$, then the thrust is offset to put it through the C. G. This of course causes an initial thrust - $\overline{VG}$ misalignment which is detected and corrected by the steering equation.

2. For Case II the simulation is of an initial alignment of the thrust through the C. G. and along $\overline{VG}$. This is done by rotating the body opposite and equal to the C.G. offset as well as making the thrust rotation to put it through the C.G.

III. RESULTS

A. For Case I

Figure 2 is the smoothed pitch and yaw gimbal angle vs time data from the simulation. The initial thrust - $\overline{VG}$ misalignment causes the system to rotate the vehicle until thrust - $\overline{CG}$ - $\overline{VG}$ alignment is obtained (pitch ≈ -1.3°, yaw ≈ -1.1°) then to smoothly track the C.G. movement from about 40 seconds to the end of the burn.

B. For Case II

Simulation data is presented in Figure 3 for both the 5 point table look up and straight line C.G. location input. As mentioned before, these two systems represent extremes in the forceing function. Both are controlled very well by the system, the differences in gimbal angles never exceeding 1.2° in either channel, and the system coming to the same terminal attitudes in both cases. The overall attitude change during the maneuver being 1.03° in pitch and .15° in yaw.

III. CONCLUSIONS

For the C' mission LOI maneuver, neither the Case I nor the Case II alignment techniques produce gimbal angle excursions above 1.4°. The Case I procedure does produce initial gimbal rates much larger than those experienced in Case II which are due to C. G. motion alone.

Neither case produces gimbal angle changes considered undesirably large.

Francis La Piana

2014:bjh:FL F. La Piana

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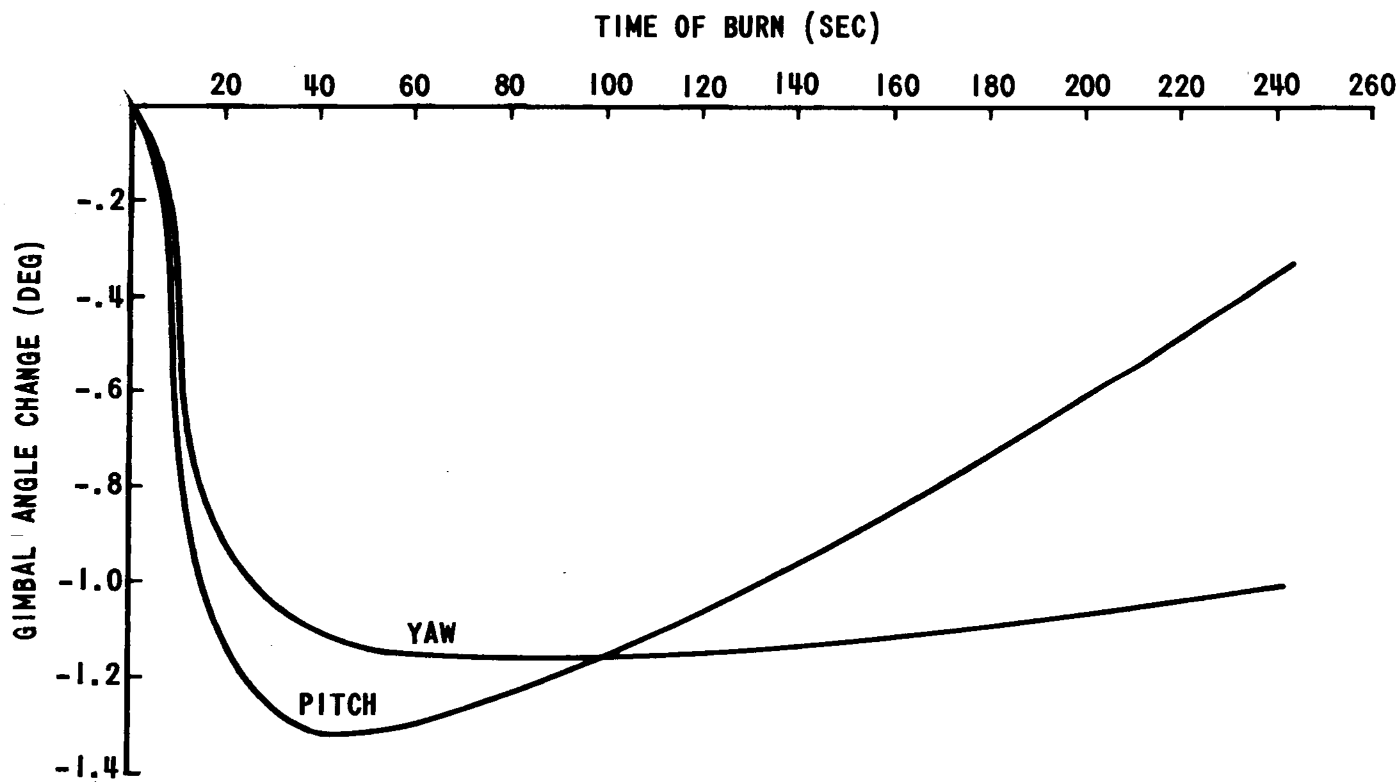

FIGURE 2 - CASE I: VEHICLE ALIGNED WITH VG. THRUST OFFSET TO GO THROUGH C.G.

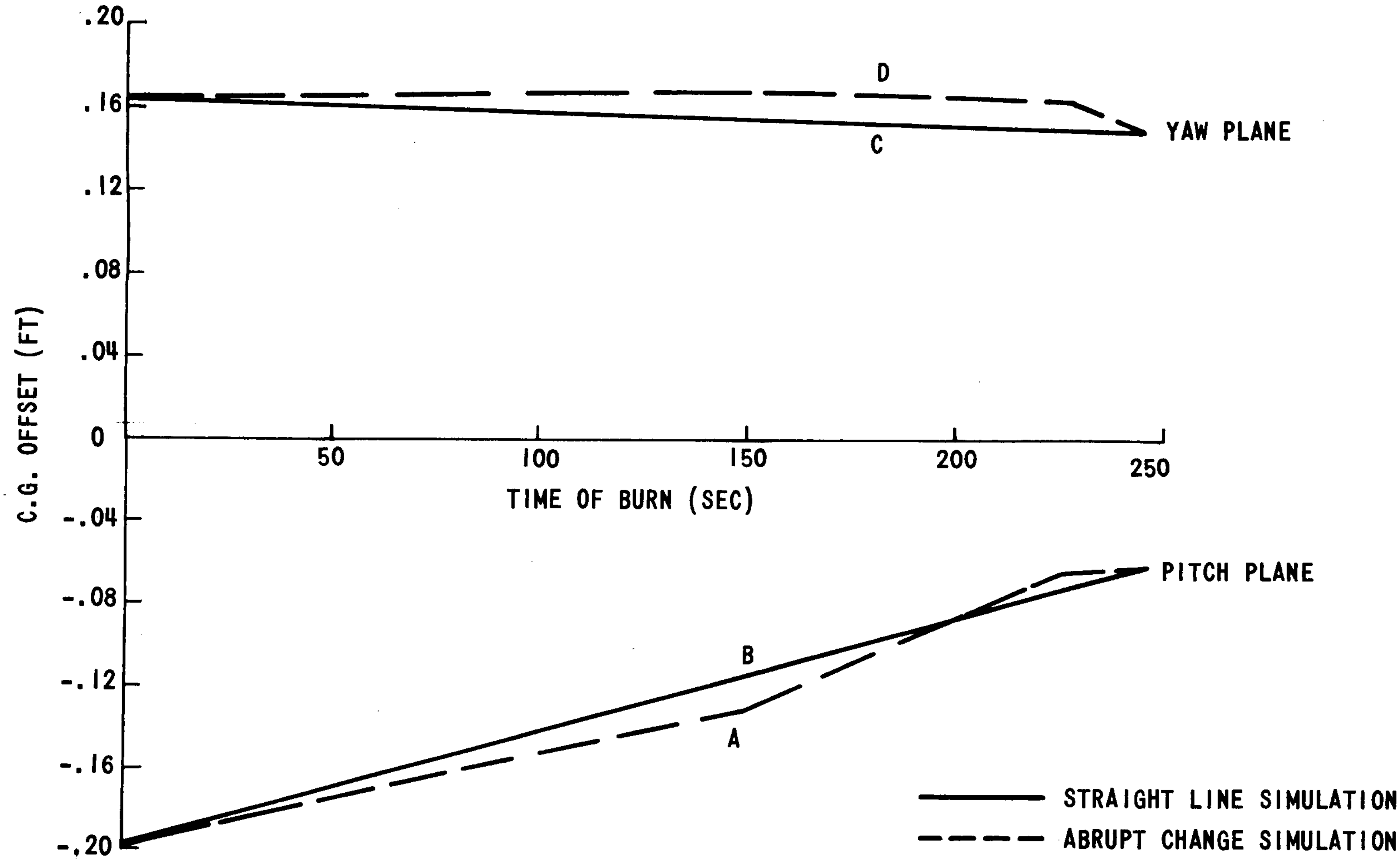

FIGURE I - C.G. POSITION VS. TIME

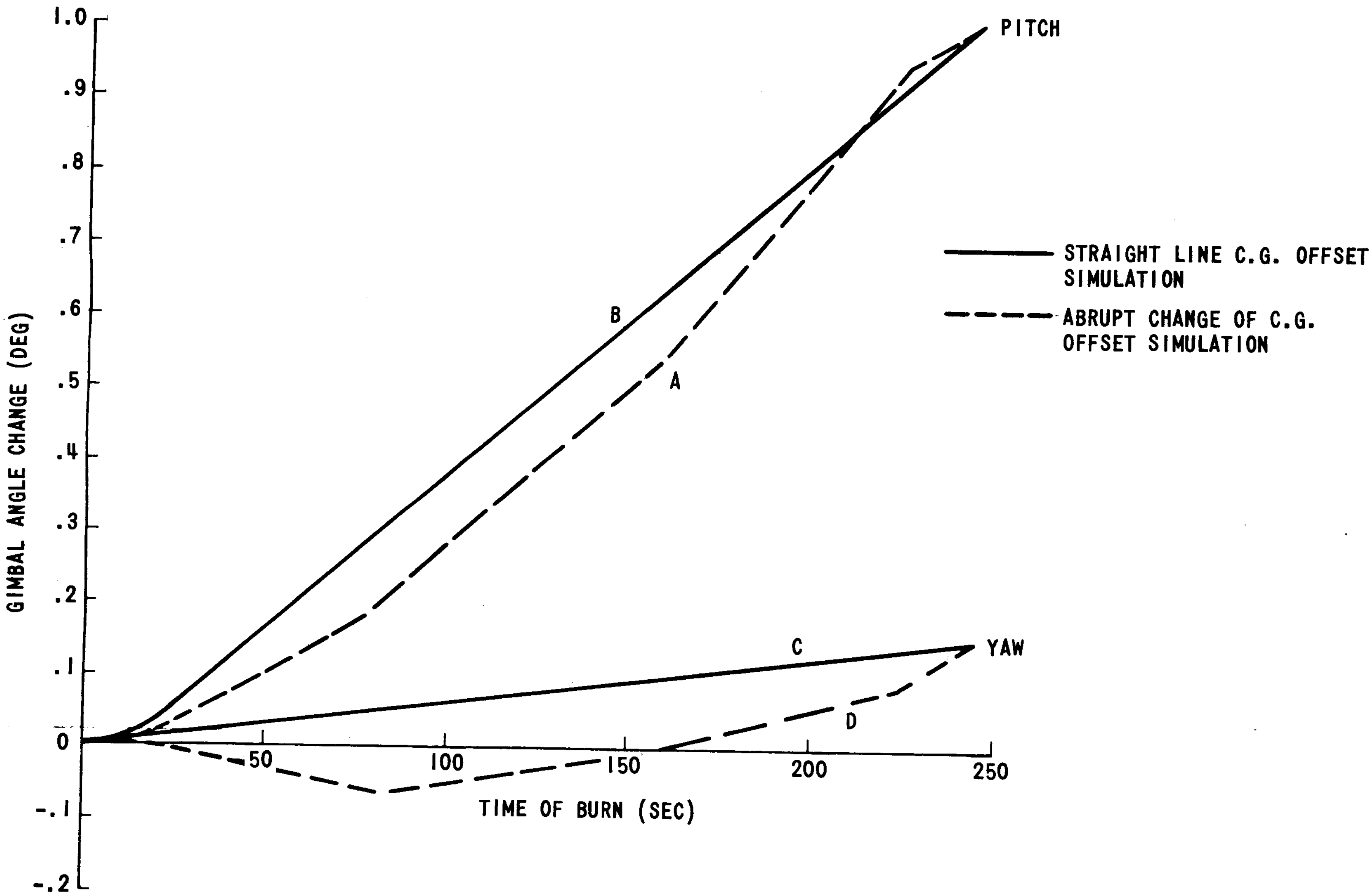

FIGURE 3 - CASE II: THRUST ALIGNED WITH VG. VEHICLE OFFSET TO GET THRUST THROUGH C.G.

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